RESURVEY OF RESISTIVITY BOUNDARY OF OHAAKI GEOTHERMAL FIELD,.1975-1992

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ABSTRACT - Close-spaced resistivity measurements along ten traverse lines crossing the resistivity boundary of tlie Ohaaki Geothermal Field were first measured in 1975 and remeasured in 1992. The 1992 resistivity profiles were similar in shape to the original ones. On both occasions very sharp resistivity boundaries were delineated along tlie southern and south-western edges of tlie Field where apparent resistivity rises sharply over a horizontal distance of a few hundred nietres from 2-5 ohm m on the inside of the Field to 20-50 ohm m on the outside. On two of the southern lines the resistivity boundary appears to have moved outwards by about 100 m, and on two others the outward movement may be as niuch as 20 m, but this is of the same order as the survey resolution.

Over the 17 year interval apparent resistivity values have dropped slightly at most measurement sites. Some of this change (up to 10 percent) may be due to calibration errors and measurement difficulties. The decrease is more pronounced on the inside of the Field where apparent resistivities have declined by up to 30 - 40 percent. This is thought to be caused mainly by the disturbing effects of the new drillholes and steam pipes that have been installed since 1975, and by changes in the watertable.

In the north-west of the Field, movement of the resistivity boundary could not be clearly detected because of reduced resolution of the survey over this region and because of large disturbances to the signal from buried conductors such as the earth mat at tlie Power Station, pipes and drillhole casings.

INTRODUCTION

As part of the exploration phase in the development of the Oliaaki Geothermal Field, a resistivity survey was made in 1975/76 (Risk et al, 1977) using close-spaced measurement points which had been accurately located relative to permanent Bench Marks, Measurements along 10 of these lines in the south and west of tlie Field (which had originally been measured in November and December 1975) were repeated in November 1992, 17-year years later, in order to deterniine whether the resistivity boundary zone had moved or changed. It was of particular interest to assess whether any changes had resulted from the exploitation of the Field since the commissioning of tlie Oliaaki Power Station in 1989.

An attempt at monitoring resistivities in geothermal Fields was done over a 2.5 year interval at the Cerro Prieto Field by Wilt and Goldstein (1984). They used an in-line dipole-dipole array with electrodes 1 km apart to look for large-scale changes. They found a rather complex pattern of resistivity changes whose dominant feature was an annual 5 percent increase in resistivity over the production zone of tlie Field which they attributed to dilution of reservoir fluids.

FIELD MEASUREMENTS

The transmitter and receiver sites for the part of the original survey which was repeated are shown in Figure 1. Points Ti and T2 show the locations of the current electrodes forming the transniitter; T1 is near the centre of the Field, and T2 is about 2 km south of the southern boundary of the Field. The transmitter location was kept constant throughout each of the surveys.

In 1992, measurements of the signal strength were made at receiver sites spaced at 50 m intervals along the lines B, C, D, E, F, G, J, K, L, N (see Fig. 1). Except for lines J and L these sites were the same (within about 10 m) as those used in 1975. Because of the recent construction of the Power Station and the pipe-work leading to it, it was not possible to repeat the measurements along the original lines H, I, J and L. The scope of tlie remeasurement project was insufficient to allow remeasurement of the lines to the north and east of the Field, or to repeat the 1975 measurements made using the current electrode pairs T1-T3 (north-west) and T1-T4 (east).

Although the layout and method for making the measurements in 1992 was the same as used in 1975, completely different instruments were used for both transmitter and receiver. The accuracy of calibration of all the instruments is hard to assess, but it is expected that tlie apparent resistivities have been measured to within about five percent on each occasion, and that the 1992 data should be more accurate than those obtained in 1975. Thus, measured differences greater than about 10 percent should represent real changes.

RESISTIVITIES

Both the 1975 and 1992 field data (currents, electric field strengths, geometric data etc) were analysed using the same standard programs to obtain apparent resistivities at each receiver site. Figures 2 and 3 show plots of apparent resistivity versus horizontal distance from tlie centre of the Field for eight of the ten lines.

Tlie left of each plot corresponds to the inside of the Field where the apparent resistivities are smallest (2 - 5 ohm ni). Although the lines traverse only a few hundred metres into the Field, measurements from other resistivity surveys (Risk et al 1970) show that a low resistivity anomaly of nearly constant value continues right across the Oliaaki Field, The resistivity boundary zone for each line is thus definable as the zone at the edge of the Field over which the apparent resistivity increases above this average 'inside' level to a nearly constant larger value typifying tlie outside of the Field, On most of tlie lines tlie apparent resistivity increases by an order of magnitude across the boundary zone and levels off on the outside of the Field at values of the order of 20 - 50 ohm m.

Experiments in 1973-75 showed that some arrangements of tlie current electrodes allow a clearer definition of the resistivity boundary zone than others. The best electrode arrangement was found to be similar to the Schlumberger layout for which the receiver sites are near the mid-point of tlie two current electrodes. Thus, for tlie repeated part of the survey using current electrodes T1 and T2, clearest definition of the boundary would be expected along the southern sector. The 1992 survey confirmed this. Measurements were also made in the north-western sector with the current electrode pair T1-T2, but, as expected, the boundary definition was not as sharply defined as in the southern sector.

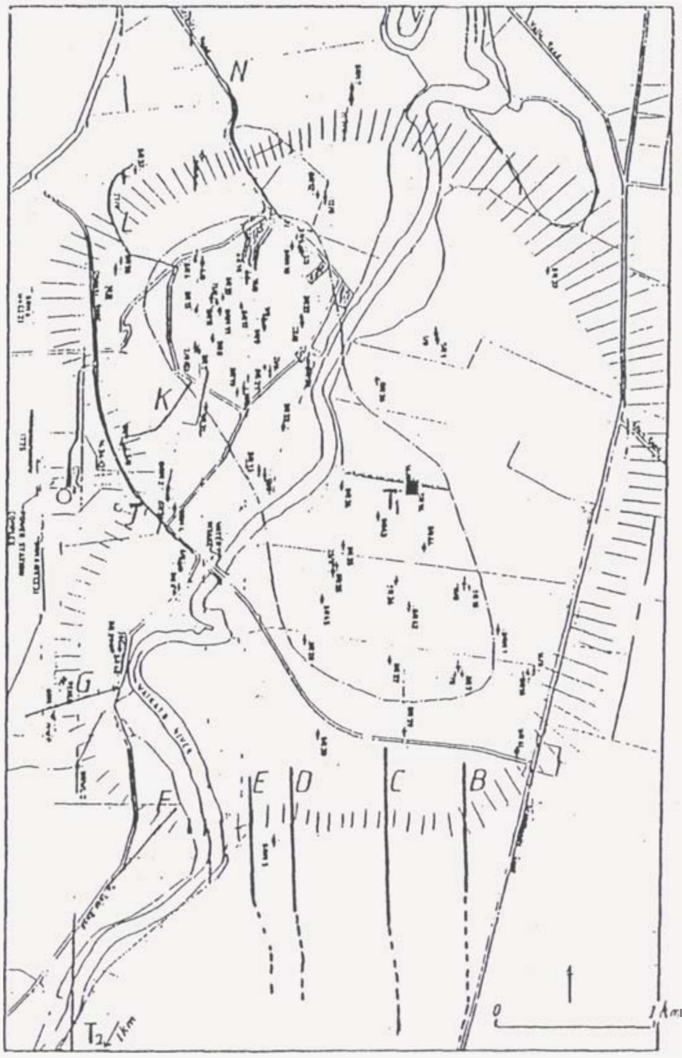

Figure 1: Layout of Multiple-source bipole-dipole array at Ohaaki Geothermal Field. T_1 and T2 are current electrodes. Measurements with receiver array were made along lines B, C, .. N, at 50 m intervals.

Lines B and C

Over the southern parts of these lines (Fig. 2) very little change was found between the resistivities measured in 1975 aiid 1992, The sharp rise in apparent resistivity over the boundary zone occurs in the same place (to within about 25 m). Thus, there has been no detectable horizontal movement of the resistivity boundary. However, on the inside of the Field apparent resistivities in 1992 were significantly smaller (by up to 40 percent) than in 1975.

Lines D and E

These lines are close together and cover a small region studied in detail by separate resistivity and magnetic surveys in June 1973 (Risk, 1981). This detailed work revealed some fine structure (i.e. electric transients, anomolous electric field directions aiid resistivity values) coincident with the boundary zone. In the 1975 survey, similar fine structure was found on lines D aiid E. But in tlie 1992 resurvey, a larger area was surveyed with the lines extended to both north and south and the fine structure was no longer found.

Coniparison of the 1975 and 1992 data shows that, in the zone where the fine structure had been found in 1973 and 1975, the apparent resistivities are much snialler now (ca. 3 ohm m, Fig 2). Thus, the inside edge of tlie resistivity boundary appears to have moved south by about 100m. Tlie anomalous zone now appears to contain low resistivity material. A possible explanation is that the original fine structure was caused by east-west fissures on the high resistivity side of the boundary, and that this region has recently been flooded with geothermal water. A reinjection well (BR30) lies only 600 m to the north-west.

Lines F and G

These lines are in the southwest corner of tlie Field. The curves show large and sharp steps in resistivity across the resistivity boundary. The 1992 curves are similar in shape to the 1975 ones, but are slightly offset, implying that the 1992 resistivities are about 10 - 20 percent snialler than the 1975 values. The boundary also appears to have nioved southwards by a small amount (up to 20 m), but as this is about the same as the resolution of the survey, the movement is not certain. Near the outside of line G, the 1992 measurements are disturbed by the presence of tlie shallow well BRM9, which was not there in 1975.

Lines J and L

Tlie original line J could not be remeasured since it now runs through the the Power Station site. In 1992, measurements were made along a new line J which runs along Oliaaki Rd past the Power Station. These data (not shown on Figures 2 and 3) are considerably disturbed near tlie Power Station by effects caused by the earth mat at the Power Station, the network of pipes, and the presence of other conductive objects in contact with the ground.

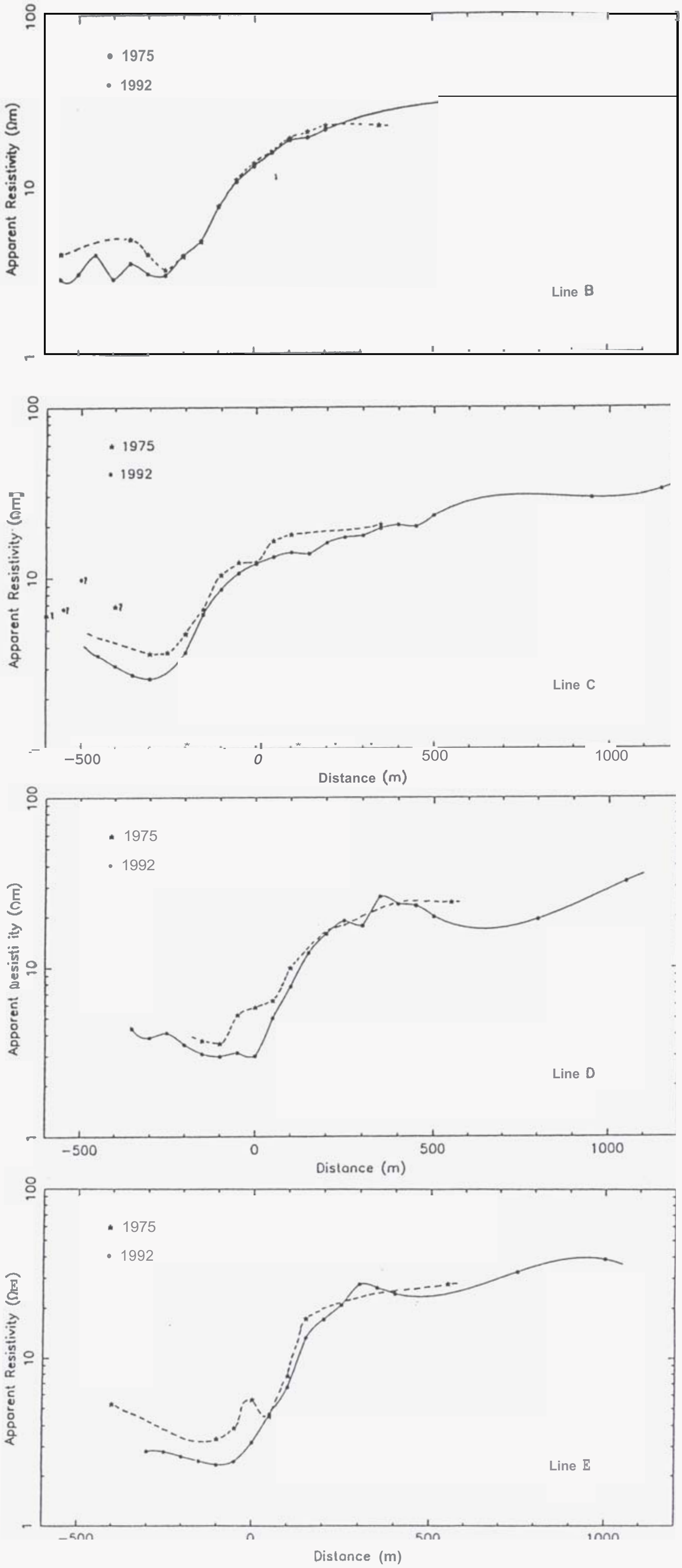

Figure 2: Apparent resistivities measured along lines B, C, D and E in 1975 and 1992.

Line K

This line runs from the old Loop Road to near bore BR5 and follows an old access road which is little used now and is some distance from the network of steam pipes. The curves on Figure 3 for 1975 and 1992 have similar shapes and resistivities, but the 1992 curve does not rise as steeply as that for 1975. The differences are more likely to be due to the disturbing effects found on nearby Line J than to movement of the boundary.

Line N

Both sets of measurements were made along Piripiri Road. In several places scrub and blackberry encroach right to the edge of the road, which made it difficult to lay out the 50m x 50m receiver array. On both surveys this appears to have caused larger-than-usual measurement errors accounting for the scatter of data. On average, the 1992 data are about 20 percent smaller than the 1975 data, and the curves have similar shapes suggesting little change of the resistivity boundary since 1975. However on line N, the resistivity boundary zone is not well delineated by either survey. This appears to be because the (T1-T2) transmitter orientation is not appropriate for this line.

COMPUTER MODELLING

The nearly circular shape of the Ohaaki Geothermal Field as well as the geometric arrangement of electrodes, with one electrode at the centre and the other well outside the field, mnkes this problem well suited to- analysis with computer modelling using axially symmetric models (Bibby 1978). With this kind of modelling, the field is simulated at a stack of (up to 100) concentric annular shaped rings. An example of such a theoretical model is given in Figure 4a. The centre of the Field is at the left-hand side, with the boundary of the Field at ca. **2** km from the centre. **All** cross-sections through the centre of the Field are the same.

This model tests the basic premise underlying the use of this resistivity resurveying method; i.e. whether it is possible to detect lateral movements of a vertical resistivity boundary. The model simulates boundary movements and assesses the resulting effects on the apparent resistivity profiles. This is illustrated in Figure 4. Model (iii) **has** the boundary in its initial position. In models (ii), and (i) the (vertical) boundary has been moved. respectively 100m and 200m towards the centre of the Field. Indeed. clear corresponding inward movements of the theoretical apparent resistivity curves can be seen, verifying the viability of the method (Fig. 4b).

A series of other models were also run. These included sloping boundaries and simulating a gradual increase in resistivity across the boundary zone. Various different resistivity-depth profiles were also investigated. This work indicates there is a certain amount of ambiguity in the interpretation process.

DISCUSSION

The eight resistivity profiles remeasured at the same sites in 1992 are all similar in shape to those of the original survey in 1975. Sharp steps of an order of magnitude in apparent resistivity were found on both occasions in the south and south-east of the Field. This degree of repeatability suggests that the experiment is soundly based and that the Schlumberger-like electrode arrangement is appropriate for monitoring the resistivity boundary. The pattern of changes is simpler than that found at Cerro Prieto with the in-line dipole-dipole array (Wilt and Goldstein 1984). This suggests that the in-line dipole-dipole array is more prone to disturbance by minor influences than the array used here.

Any lateral movement of the boundary of the hydrothermal reservoir is expected to be reflected as a movement in the place where the sharpest rise in apparent resistivity occurs. The lines in the south and south-west of the Field **show** sharp resistivity boundaries for which lateral movements of more than 20 - 50 m should have shown up. Such movements between 1975 and 1992 were detected on only two lines (E and F) where the resistivity boundary appears to have moved outwards by about 100m. Since bore BR30, one of the main reinjection bores, lies only 600 m to the northeast of these lines, the provisional interpretation is that **a** southward displacement of reinjected thermal water has caused these changes, However, the position of the resistivity boundary has not changed significantly on Line C or B which lie to the east, close to injection bore BR29. Small outward movements of about 20 m (at the limit of resolution for the experiment) are provisionally inferred for line G which lies 350 m south of injection bores BR39/40, and nearby line F (1000 m south of BR39/40).

Another trend that has occurred over the 17 year interval is that the 1992 resistivity values are systematically smaller than those measured in 1975. The decrease is more pronounced on the inside of the Field where apparent resistivities have declined by about 30 - 40 percent. This appears to result from several causes. Calibration and measurement errors may account for up to 10 percent of the difference. There has also been a major change, between the surveys, in the number of drillholes in the Field and in the emplacement of steam pipes and other metal structures at the surface. One would expect any additional pipework near electrode T1 to affect the measurements. The biggest change here is that nearby drillhole BR14 is now connected by steam pipes to the other neighbouring bores. **A** low resistance was measured between electrode T1 and BR14. Thus, in 1992 but not in 1975, some of the current will have entered the ground through bores BR43 and BR44. This increases the effective size of the electrode. Another possible cause of the resistivity decrease is the change in the watertable level or of the conductivity of pore-water over the south of the Field. The implications of these effects has not yet been fully examined.

ACKNOWLEDGEMENTS

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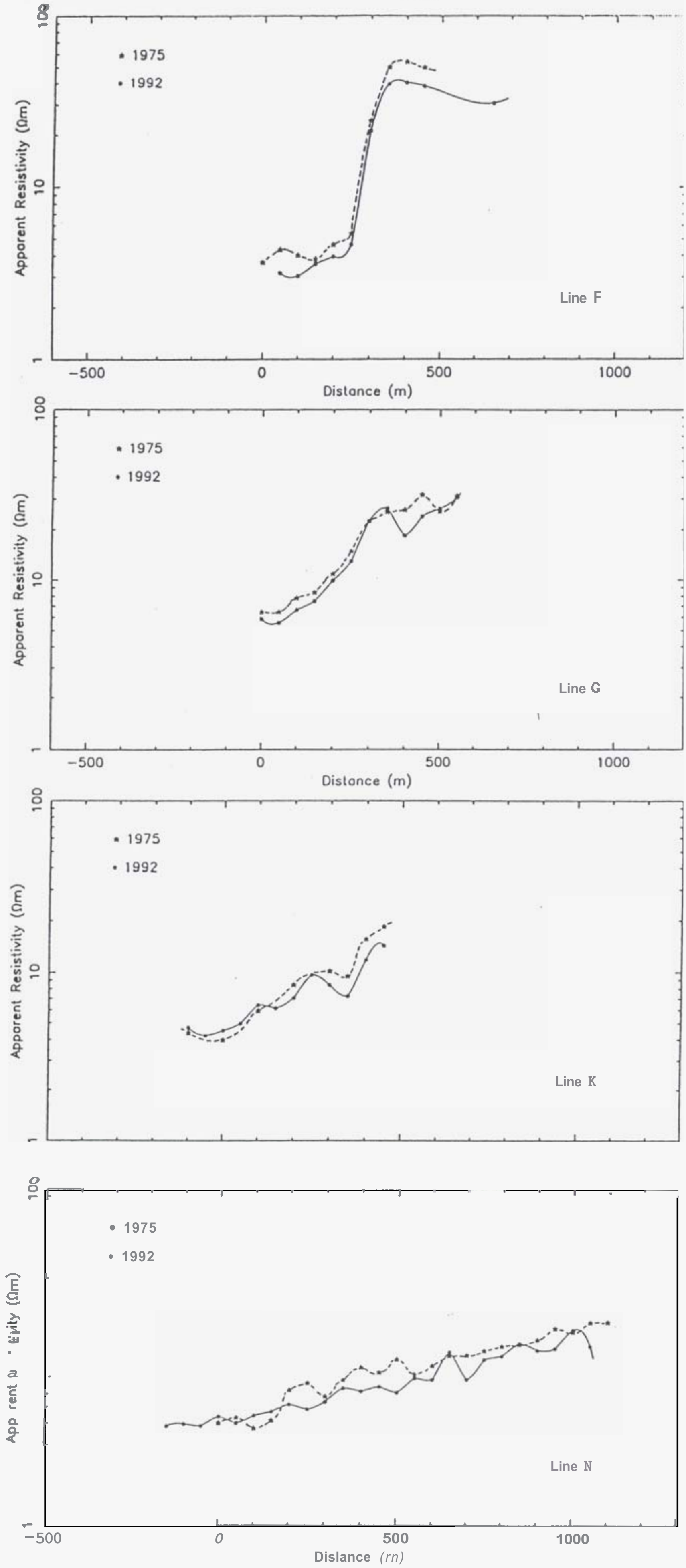

Figure 3: Apparent resistivities measured along lines F, G, K and N in 1975 and 1992.

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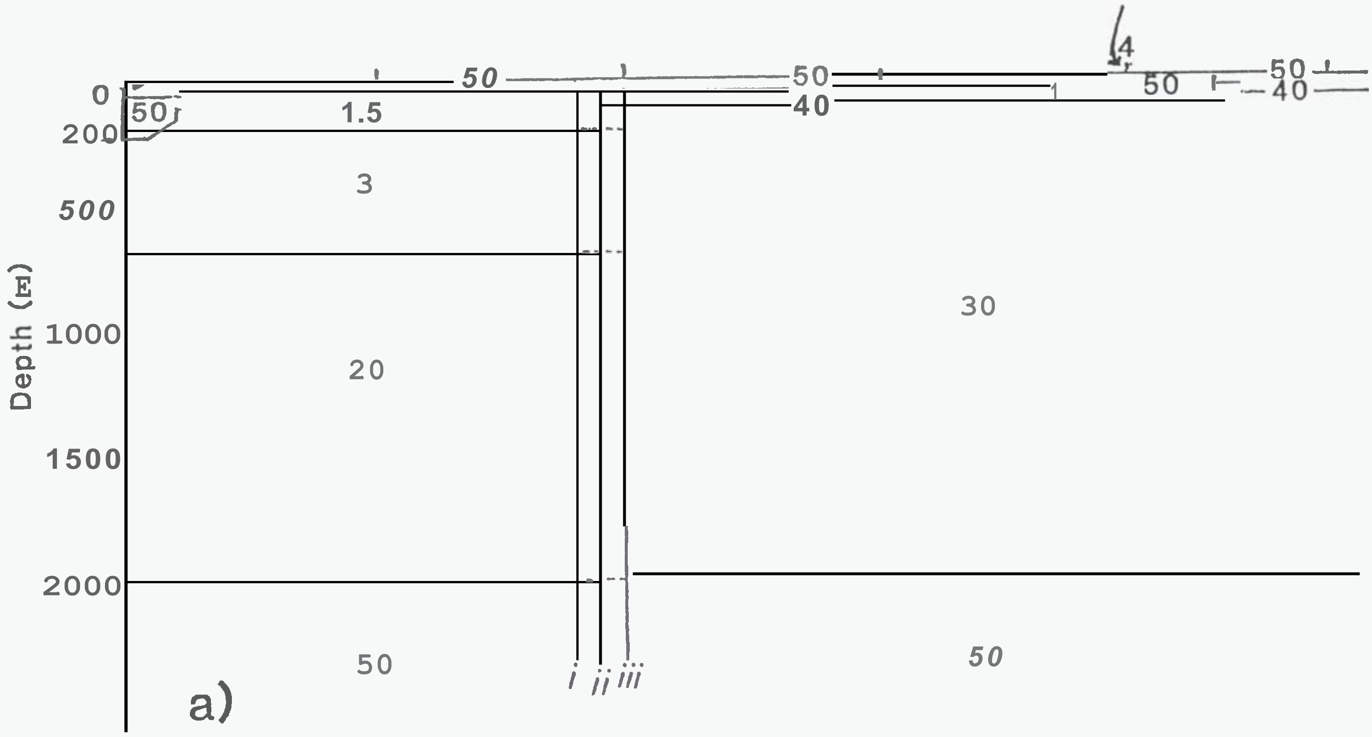

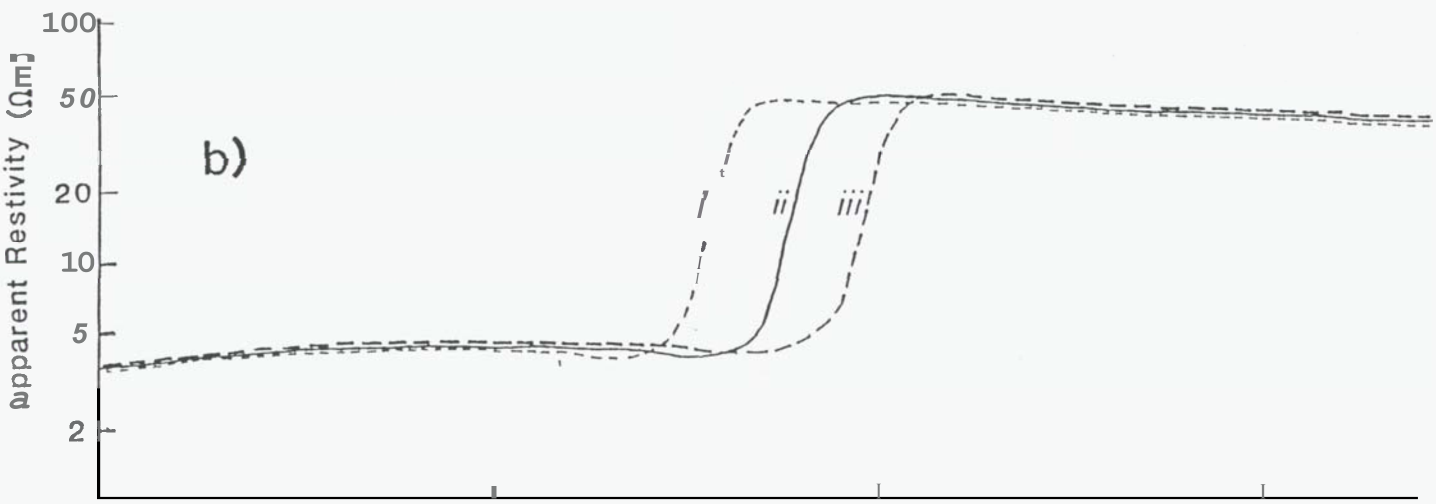

Figure 4: a) Section along radius of axially symmetric model of resistivity structure of Ohaaki Geothermal Field. Models have vertical boundaries at the edge of the Field at distances from the centre of :- (i) 1.8 km, (ii) 1.9 km, (iii) 2.0 km.

b) Apparent resistivity curves for models i) ii) and iii).